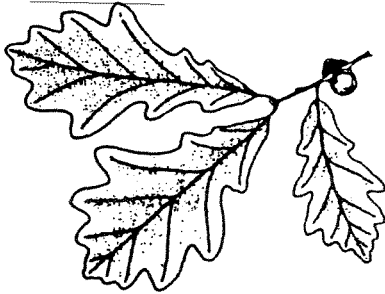


# MEASURING FERTILIZER RESPONSE IN MIXED SPECIES HARDWOOD STANDS<sup>1</sup>

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**ABSTRACT.**--The interpretation of fertilizer nitrogen response of mixed species hardwood stands is discussed. Data from a regional fertilization study in southern New York are used to illustrate the interpretation of response measured on increment cores taken from black cherry, white ash, red oak, sugar and red maple, and basswood. The effect of uncontrolled variability due to climate and insect defoliation is highlighted.

## INTRODUCTION

Nitrogen is often the limiting factor in tree growth, and many fertilization experiments have been installed in eastern hardwood forests (Auchmoody and Filip 1973). There has been surprisingly little formal discussion of measurement problems and interpretation of response in such experiments. Given the significant investment required by forest fertilization trials, it seems worthwhile to evaluate some of the literature and to illustrate the problems encountered in our study of N response in northern hardwood stands in New York.

## THE NATURE OF RESPONSE

### A Single Species Perspective

Concepts recently advanced by Miller (1981) for conifer plantations and Attiwill (1979) for eucalypts provide a useful framework for explaining the results of fertilization in hardwood stands, recognizing that marked differences in N distribution may exist. Considering an even-aged stand composed of a single species (or of species with similar nitrogen requirements), there are three nutritional stages in its development. In Stage 1, there is a high nitrogen requirement as the crown and root system develop. The trees do not dominate the cycling of nitrogen on the site as they will later; thus, nitrogen inputs from precipitation or mineralization may be taken up by other plants (Marks 1974; Safford 1974) or lost from the site (Vitousek and Melillo 1979). As a practical consideration, the nitrogen capital inherited by the young stand may limit its rate of development (von Althen 1976; Auchmoody 1982).

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In Stage 2, as canopy closure nears completion, nitrogen cycling mechanisms dominate. Annual nitrogen uptake is high, immobilization in coarse woody biomass is low and much of the annual uptake is either returned in litter, or withdrawn into fine twigs and phloem, to be remobilized the following growing season (Lutz and Chandler 1946; Mitchell 1936). Miller (1981) stressed that the critical difference between Stages 1 and 2 is the amount of nitrogen needed annually for production of the foliage. Therefore, a reduction of foliage biomass in the stand, as through thinning or insect defoliation, could effectively revert the stand to Stage 1, in terms of the N demand for foliage production.

In stands with low initial nitrogen capital, or in low rates of mineralization, Stage 3 is reached when nitrogen mineralization is less than tree requirements. Some stands may never reach Stage 3 (Miller 1981); other stands on impoverished sites pass directly from Stage 1 to Stage 3.

Thus, there are three conditions when a stand will respond to nitrogen inputs: prior to canopy closure, when demand is high and the stand is most dependent on nitrogen mineralized in the soil; following reduction of foliage biomass from a closed canopy; or after "late rotation" deficiencies develop.

#### An Individual Tree Perspective

Increased stem growth after fertilization is associated with increased foliar nitrogen levels (Mitchell and Chandler 1939; Brix and Ebell 1969; Brix 1971; Weetman and Algar 1974). Two mechanisms have been proposed to explain this coupling: increased photosynthetic efficiency and increased leaf area.

Greater production of assimilates per unit area of needle surface (Keller 1967; Brix 1971) has been advanced as the major mechanism of the growth response to added N (Penning de Vries et al. 1975), although the increase is no more than about 25% (Brix 1971). Increased leaf area results from increased number and size of leaves (Wells et al. 1975; Mader and Thompson 1969; Mitchell and Chandler 1939; Stone and Christenson 1974). Both mechanisms may occur (Miller et al. 1976).

Perspectives of individual tree and whole stand response agree in that response to added nitrogen involves increasing the photosynthetic machinery of individual trees.

#### A Mixed Species Perspective

Evaluating the overall response of mixed hardwood stands to N fertilization is made difficult because species respond differently (Mitchell and Chandler 1939). Additionally, species respond differently to density and crown position. A variety of other variables also have differential effect on species, or even individual trees of the same species. The effect of frost, for example, will depend on when it occurs and its severity; susceptible species, or those just leafing out, may suffer setback in growth relative to other species in a stand. Insect defoliation is often somewhat or absolutely selective. In such cases, defoliation of one species may stimulate growth of other species, through increased moisture availability (e.g. Hinckley and Lassoie 1981). Hence growth measurements of fertilized stands must extend over several years to assess interactions with other variables (Safford 1973).

Using foliar N as an index of N availability and radial growth as a measure of response, Mitchell and Chandler (1939) classified northern hardwood species into three classes, based on shape and magnitude of the response curve.

1. "Nitrogen deficiency tolerant" species that attain maximum growth with relatively low nitrogen availability. These species are subordinate or missing from high nutrient sites;
2. intermediate species, which outgrow the tolerant species at moderate nitrogen levels; and
3. nitrogen demanding species, which require relatively high levels of available nitrogen for maximum growth. At moderate levels these are outgrown by the intermediate species, and do not occur on the lowest fertility sites.

Subsequent research has confirmed the differential response of northern hardwoods to added nitrogen. Foliar response is usually immediate and definite (Leaf and Watterston 1964; Leaf and Bickelhaupt 1975; Lea et al. 1979a; Lea et al. 1980), and N levels increase in proportion to the amount of N added, whether or not stem growth increases (Ellis 1979; D. Stone 1980). Magnitude and duration of stem growth in response to added N have proven more variable. Wide variations in plot density, pretreatment growth rates, and other site factors can overshadow fertilization effects (Auchmoody and Filip 1973; Auchmoody 1982; Safford 1973; Salonijs et al. 1982; Hall et al. 1980; Miller and Tarrant 1983).

Pre-treatment growth rate influences response to treatment. Growth rates of individual trees vary according to species, crown position, and quality of the site. Trimble (1968, 1969), studying growth of several hardwood species, concluded that diameter at breast height (DBH; 1.37 m) was the best predictor of growth potential in uniform stands composed of a few species with similar growth characteristics. In more diversified stands, crown class was a better indicator of potential growth. Therefore, crown class would be the preferred measure in stands composed of several species with differing growth characteristics, or uneven-aged stands. Individual trees grew faster at low stand densities, which also favored growth of lower crown class trees.

Safford (1973) concluded that a measure of tree vigor should be incorporated into fertilization studies. Both rate of growth of all trees before treatment, and the growth rate of control trees bore on evaluation of treatment response. Safford used relative basal area growth (cm<sup>2</sup> per 100 cm<sup>2</sup> basal area per tree) for 8 years before treatment as a covariate to adjust treatment means.

Besides differential response to added nitrogen, hardwood species appear to tolerate "crowding" differently (Gingrich 1967). Relative density measures have been developed (Stout et al. In press) to overcome difficulties in using absolute stand density measures which vary according to tree size (DBH) and species composition of the stand. Relative stand density is an index of stand crowding, and many measures of it have been proposed (Curtis 1970). A relative density measure based on tree-area equations is used in management of Allegheny hardwoods (Marquis et al. 1984) and the approach appears applicable to hardwoods in general. Thus far, however, the utility of relative density measures as predictors (or covariates) of fertilization response has not been assessed.

The pattern that emerges is complex. The complexity arising from differential species response to added nitrogen and variable stand density can be controlled to some extent by judicious selection of experimental stands. Factors such as species composition, stand relative density, and tree size can be considered endogenous sources of variation. There remain the exogenous sources, biotic (i.e. insects and disease) and abiotic (primarily weather related), over which little control is possible. On an individual tree basis, their past effects are incorporated into pretreatment growth.

#### Measuring Response

Fertilizer response may be evaluated differently depending upon what is measured and where, and what size tree is measured. For example, D. Stone (1977, 1980) presented 10-year results of a study for which the 7-year results had been reported by Carmean and Watt (1975). Different conclusions were reached, partly because response had peaked at 4 years, and the periodic annual diameter growth of fertilized trees calculated after 10 years, was smaller than at 7 years. More to the point, Stone (1977, 1980) excluded one of the control plots used by Carmean and Watt (1975) on the grounds of abnormally low growth, and also trees larger than 21.5 cm DBH because they were too few for meaningful comparisons.

Radial and height growth are measures of response independent of tree size (Shea and Armson 1972), whereas cross-sectional area growth (basal area increment) and volume growth obviously depend on tree diameter. Comerford et al. (1980), in a detailed study of red pine (*Pinus resinosa* Ait.) response to potassium fertilization, concluded that volume or biomass was the most appropriate measure. These may not be the most appropriate measures for high value hardwoods, where quality of the merchantable bole may determine whether fertilization is economically justified.

A point not often considered in evaluating fertilizer response is that once treated trees have responded, it is misleading to compare them to unfertilized trees of the same pretreatment diameter

or volume (Miller 1981). Such comparisons may lead to the erroneous conclusion that fertilization has depressed growth of older trees where current annual growth increment has already peaked, or that the positive effect of fertilizer is very long lasting, in younger trees that have not reached this maximum growth rate. These pitfalls are easily avoided through use of regression techniques that adjust all trees to a common diameter<sup>3,4</sup>.

#### METHODS

The experiments were designed to explore the influence of site fertility on tree growth, especially the differential response to nitrogen. Nitrogen was chosen because Mitchell and Chandler (1939) found it the only commonly limiting nutrient for hardwoods in the Northeast. Plots were installed over a 3-year period (1967-1969). All experiments were designed as rate trials, with from 0 to 672 kg/ha of nitrogen applied in each of two applications, 5 years apart. Thus, plots established in 1967 and treated with 672 kg/ha of nitrogen were treated in 1972 with the same amount, for a total of 1344 kg-N/ha. Nitrogen was applied as ammonium nitrate. Fertilizer was broadcast uniformly by subdividing each plot; treatments were applied between May and July. The objective was to extend the work of Mitchell and Chandler by concentrating on stem response on a plot (stand) basis. Black cherry (*Prunus serotina* Ehrh.) was included in this study in addition to some of the same species examined by Mitchell and Chandler (1939).

All plots were located on New York State Forests or Game Management Areas. Sites were selected in uniform stands of desirable hardwoods of medium to large pole size on well to somewhat poorly drained soils. Stands with recent cultural work were preferred to obtain relatively uniform stocking. Some stand characteristics are given in table 1; detailed descriptions of the experimental locations are given by Stanturf (1983). Locations are shown in figure 1.

<sup>3</sup>Auchmoody, L.R. Unpublished manuscript. Evaluating growth responses to fertilization.

<sup>4</sup>Stanturf, John A.; Stone, Earl L., Jr.; McKittrick, Russell C. Unpublished manuscript. Effects of added nitrogen on growth of hardwood trees in southern New York.

TABLE 1.--Characteristics of the stands.

Location	Cattaraugus	Whig Street	Connecticut Hill	Chenango Black Cherry	Chenango Maple-Basswood	Schoharie	Hooker Hill
Elevation (m)	692	620	518	543-549	558	613	658
Slope (%)	0-15	30	10-15	0-3, 5-8	0-5	0-5	0-5
Aspect	SW	E	N	NW	N	S-SE	S
Mean diameter (mm)	960	960	890	1151	1151	1061	1061
Mean temperature (C)	6.1	6.1	7.8	7.4	7.4	7.6	7.6
1	Med. Pole-Small Saw.	Med. Pole	Med. Pole-Small Saw.	Med. Pole-Small Saw.	Med. Pole-Small Saw.	Med. Pole-Small Saw.	Sapling-Med. Pole
2	23-51	21-52	21-44	23-59	20-31	19-62	17-39
3	18.8-34.4	19.7-23.4	14.5-32.1	28.2-40.2	20.9-28.7	18.6-24.6	16.3-22.3
4	Gilpin Channery SL Rayne SL Typic Hapludults	Wharton SL  Aeric Hapludults	Mardin SL  Typic Fragi-ochrepts	Bath SL  Typic Fragi-ochrepts	Mardin SL  Typic Fragi-ochrepts	Lordstown Grav. SL  Typic Dystr-ochrepts	Lordstown Grav. SL  Typic Dystr-ochrepts

the beginning of the experiment.

range in diameters of the sampled trees.

range in basal areas before treatment; all stems 1.27 cm and larger.

#### Experimental Sites - New York

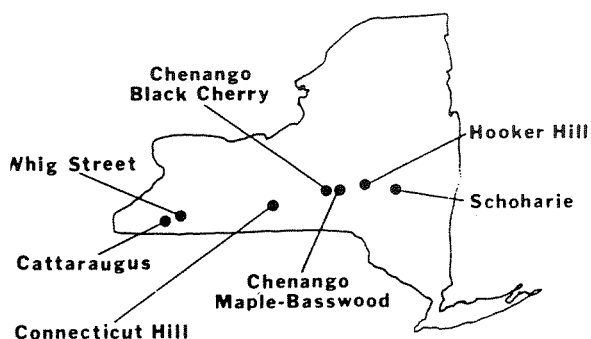


FIGURE 1.--Location of the experimental sites.

The findings of Mitchell and Chandler (1939), Chandler (1943), and Mitchell (1972) suggested that a relatively large diameter response would occur. The response variable designated in the original experimental design was stand basal area increment, identified by species. At the outset of the study it was not intended to compare growth of individual trees between measurements, or to stratify growth response by crown position. Later it became obvious that such comparisons would be necessary to arrive

at unequivocal conclusions regarding treatment effects, inasmuch as response was less than expected and often overridden by measurement error and natural mortality. More precise growth measurements were sought by taking increment cores from individual trees at breast height.

Each sampled tree was numbered, DBH was measured, and crown class estimated. Increment cores were taken at breast height, either one, or two, 90 degrees apart. All dominant and codominant trees were cored at Connecticut Hill, Cattaraugus, Whig Street, Chenango Black Cherry and Chenango Maple-Basswood, and Schoharie, whereas at Hooker Hill, at least ten dominant and codominant sugar maple per plot were sampled. Three trees of each of the other species were cored on each plot.

Cores were stored in water to which formaldehyde had been added, then measured on an Addo-X instrument (Ecklund 1950), nominally to the nearest 0.01 mm. The accuracy of the machine, however, is probably greater than the accuracy to which individual rings could be identified under the low power microscope. Cores were trimmed with a scalpel to provide a smooth transverse surface, which was especially important for diffuse-porous species. Ring-porous species were sometimes not trimmed if the growth rings were evident, and the core truly perpendicular to the stem and to the growth annuli. When two cores per tree were available, the two measurements were averaged for subsequent analysis.

In addition to radial increment, annual basal area increment after treatment, relative basal area increment (Safford 1973), and basal area increment between treatment intervals were calculated. Radial growth in successive years was highly correlated with growth in previous years.

An annual pretreatment growth rate using 10 years basal area increment prior to treatment was calculated for each tree, and used in analysis of covariance to correct for size and growth rate differences prior to treatment. This covariate was used in preference to crown class. Crown class as observed 10 or more years after fertilization could not be assumed to be independent of treatment effects. There was no a priori reason for basing the covariate on the 10 years prior to treatment, except that a shorter interval might give undue emphasis to single season anomalies.

Large annual variations in growth made it difficult to compare different species or response of a species at different locations. Below average precipitation in most of the state for several years prior to installation of the experiment, and defoliation by outbreaks of various insects probably affected the covariate differently, according to species. Defoliation probably recurred in different years in different stands during the course of the experiment. As a consequence, irregularities in the annual ring--and individual tree variability in growth and in response to defoliators or frost--affected treatment means and the pretreatment growth covariate, especially when sample size was small.

Growth response data can be analyzed in three ways: (1) adjust data by covariance and pool over all locations; (2) adjust data by covariance and examine species stand by stand; (3) examine unadjusted treatment means in individual stands. The first approach is preferred for evaluating response to fertilization--it concentrates on treatment effects, controlling variability through covariance adjustments. Pooling data over several locations increases both sample size and the population about which inferences are made (Snedecor and Cochran 1967). The third approach concentrates on the variation inherent in the stand, and response to fertilization is assessed in light of other factors affecting tree growth. This approach offers limited possibility for obtaining statistically significant results. Because few stands have species evenly distributed over plots at all treatment levels, comparisons between species lack power; in any case, inference to other populations would seldom be warranted. Although statistically naive, this approach has the advantage that growth rates can be compared to other studies and aberrant data detected. Possible interactions between tree species, treatment, and other site specific parameters may be suggested by the data.

Examination of covariance adjusted data from individual stands offers no advantage over pooling data from several stands except for a species with limited representation, or for an experiment with few locations.

Growth variables were examined for each species at the several locations separately in a nested design ANCOVA. Adjusted treatment means for white ash, black cherry, and sugar maple basal area increments were then pooled over locations to assess treatment effects in individual years. Differences in treatment means were tested for significance using orthogonal contrasts (Allen and Cady 1981). All analyses were done using the General Linear Models Procedure of SAS; significance was evaluated at the 5% level. The highest  $r^2$  and lowest coefficient of variation from the analysis of covariance were obtained with annual basal area increment data; therefore, the other response variables were not considered.

To compare species at individual locations separately, annual basal area growth for each species was combined into three treatment levels at each location: control, low, and high. The results are given as the weighted mean averages of the unadjusted treatment means, not the means adjusted by covariance.

## RESULTS AND DISCUSSION

Having abandoned stand growth as the response variable for good reason, we encountered other sources of variability. Pretreatment growth of the individual tree as a covariate was highly significant in all regressions. We did not, however, adjust for increased size of fertilized trees as Auchmoody suggested. In the few stands where lower crown class trees were cored, they had grown noticeably less than dominant and codominant trees, and were excluded from further analysis.

We compared black cherry, white ash (Fraxinus americana L.), and sugar maple (Acer saccharum Marsh.) growth response by analysis of covariance of combined data from all locations. These results are reported elsewhere (Stanturf 1983).<sup>4</sup> Briefly, we found:

1. Differential response to added N;
2. Black cherry was the most responsive species followed by white ash, whereas sugar maple actually declined in growth;
3. Overall, response was less than expected from earlier studies.

Data from various rates were combined, in order to compare growth between species at individual locations, and are shown for each stand in figures 2-10. It is apparent from figures 2-10 that the most conservative traces (i.e., those with smallest year-to-year variation) are associated with the largest sample sizes. Results from an eastern and western location (Chenango Maple-Basswood and Cattaraugus, respectively) are presented as illustrative of the results obtained at all locations.

We attributed many differences in growth to foliation by insects. Our evidence is mostly circumstantial and qualitative, gleaned from regional (usually county-wide) reports (anon. 1966-1978). In one instance, however, we observed that defoliation of sugar maple (by fall cankerworm and linden looper) was less than that of other species. In most cases, lesser growth on leaves of one species in a stand coincides with faster growth of others, supporting an interpretation based on a selective agent.

A late spring frost in 1976 may explain growth declines in several areas. Although temperature observations in the stands are lacking, climatological data indicate a widespread frost late in May (Weather Bureau 1976). Overall, this month was 1-2 degrees cooler than the long-term average for May. In 1976, the last frost occurred two weeks later than the previous year, and one week later than in 1977. We also observed severe frost damage in western New York in late May, 1979. Half expanded sugar maple leaves had extensive interveinal necrosis. Damage to white ash leaves appeared less severe, suggesting that damage had occurred before the leaves were out, some time before our observation was made.

#### Cattaraugus

**BLACK CHERRY, WHITE ASH, AND RED OAK.**--These species grew faster in response to added nitrogen (figs. 2, 3, 4). Growth at all treatment levels declined after 1973, probably due to periodic defoliation from the cherry scalloped shell moth initially, and by the fall cankerworm and the linden looper in 1975 (Anon. 1972, 1973, 1974, 1975)<sup>5</sup>. This was followed in 1977 by a dramatic upturn in growth. Prior to the decline in 1973, the growth rates of the three species were different. Black cherry in all treatments increased materially; red oak (*Quercus rubra* L.) had no such increase in growth. Fertilized white ash growth rates were elevated over controls, presumably in response to added N, but otherwise growth was constant through 1974. Thus the effect of added nitrogen on stem growth is confounded by crown defoliation of unknown varying severity. Three patterns of growth and recovery emerge from these data. Overall, black cherry and red oak grew faster at the high-N rates (figs. 2 and 3). White ash fertilized at the low rate grew faster than controls, but additional nitrogen produced no further growth increment (fig. 4).

<sup>5</sup> McKittrick, Russell C. 1975. Notebook for forest fertilization studies. On file, Department of Agronomy, Cornell University, Ithaca, New York.

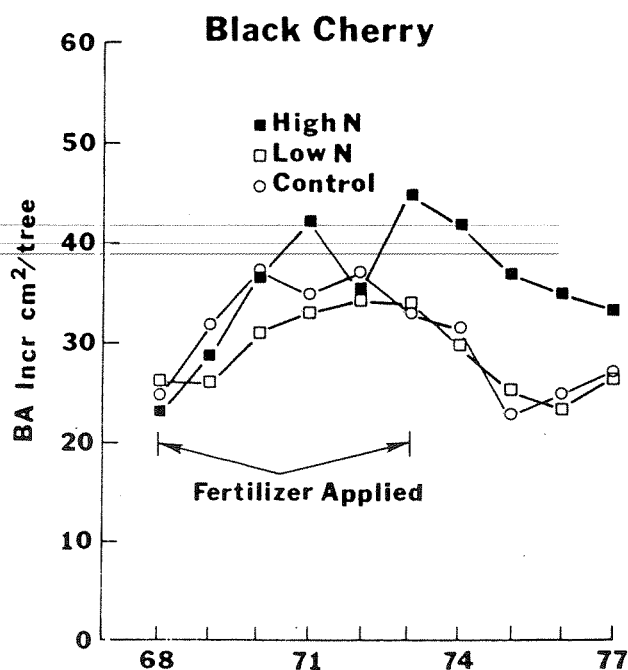


FIGURE 2.--Annual response of black cherry basal area increment to added nitrogen, Cattaraugus.

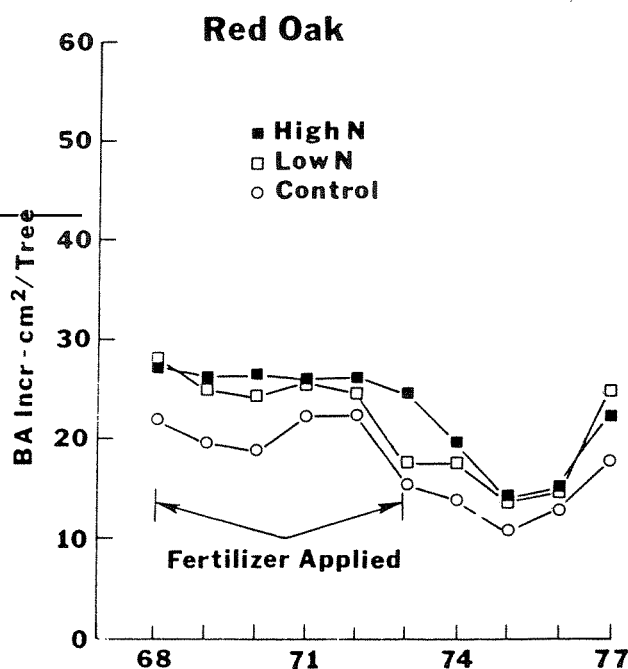


FIGURE 3.--Annual response of red oak basal area increment to added nitrogen, Cattaraugus.

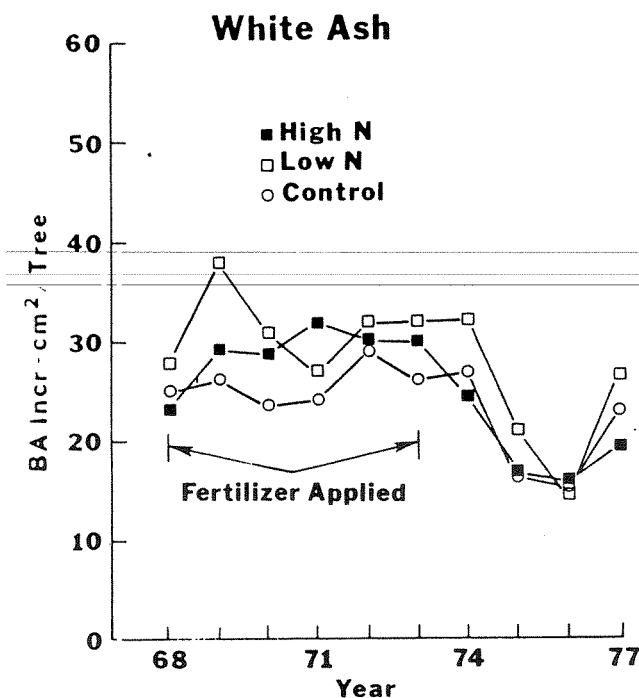


FIGURE 4.--Annual response of white ash basal area increment to added nitrogen, Cattaraugus.

Superimposed on the response to fertilization was the declining growth in response to defoliation. Controls of all species declined in basal area growth in 1973. Trees fertilized at the rates that produced the lower response (i.e., the low N rate for black cherry and red oak, and the high-N rate for white ash) similarly declined in growth in 1973. The decline due to defoliation of the trees that showed greater response to added N lagged behind that of other treatments by a year. This was most noticeable with white ash at the low-N rate. Whether this reflects differing severity of defoliation, or greater ability of the faster growing trees to refoliate in the same season as defoliation, or is simply an artifact of small sample size is unknown.

The third pattern concerns the recovery in basal area growth rates in 1977. Black cherry, red oak, and white ash at the low-N rate recovered faster than trees at the high rate, or than unfertilized trees of the same species. Once again, this may merely reflect random variability. On the other hand, herbivory could have been greater on trees treated with a higher-N rate (Mattson 1980).

Red oak was numerous only at this location, so comparison at several stands was not possible. Other studies have shown red oak to grow faster with additions of N (Mitchell and Chandler 1939; Farmer et al. 1970; Karnig 1972; Auchmoody and Smith 1977), and of P (Lamson 1978; Graney and Pope 1978). In the present study, growth at the high rate was from 16 to 61% greater than controls, with response greatest in the third year after treatment

and declining thereafter. These results are in best agreement with those of Auchmoody and Smith (1977) and Graney and Pope (1978). Both magnitude and duration of response were less than that found by Karnig (1972) probably reflecting differences in site fertility (Auchmoody and Smith 1977).

**SUGAR MAPLE AND RED MAPLE.**--Growth of sugar maple declined on all treatments during the 10 years of the experiment (fig. 5). This was probably due to the increasing crown competition after thinning in 1962, and to a variety of insect and disease problems reported from the vicinity of the experimental locations, including defoliation by the saddle prominent moth in 1968-1970 (Anon. 1973).

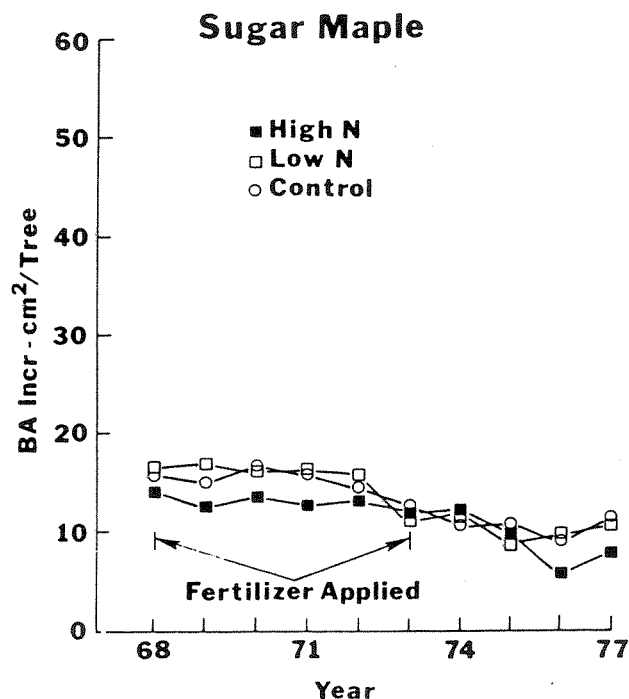


FIGURE 5.--Annual response of sugar maple basal area increment to added nitrogen, Cattaraugus.

Growth of red maple (*Acer rubrum* L.), on the other hand, did not decrease noticeably during this period (fig. 6). Radial growth of unfertilized trees was as fast as those fertilized at the highest rates and considerably faster than that of the unfertilized trees in Mitchell and Chandler's (1939) study.

Response to fertilization was negligible in both sugar maple and red maple at the Cattaraugus location (figs. 5, 6), except for a small growth increase by sugar maple, but not red maple, during the second year after the second application (1974). Interestingly, this slight increase came as other species in the stand were being defoliated by the fall cankerworm and the linden looper (Anon. 1974). We observed that defoliation of sugar maple was less

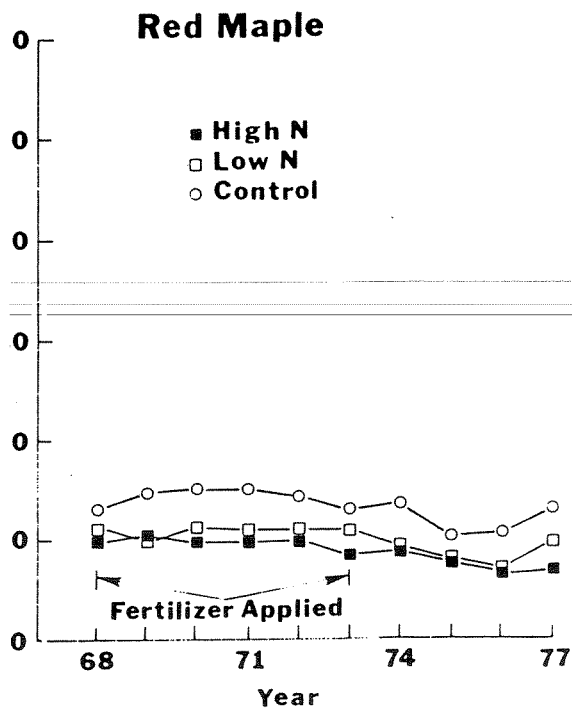


FIGURE 6.--Annual response of red maple basal area increment to added nitrogen, Cattaraugus.

e than that of other species in this stand<sup>5</sup>.  
ower growth rates for the maples in 1976,  
ially at the high-N rate, probably was the  
t of severe frost in May (Weather Bureau 1976).

#### Chenango Maple-Basswood

BLACK CHERRY, WHITE ASH, AND BASSWOOD.--The  
nse of black cherry and white ash to added N  
imilar to that at other locations (figs. 7 and  
Black cherry grew faster at the high rate;  
ash at the low rate. White ash apparently was  
s severely defoliated between 1970 and 1972 as  
cherry. A slight decline in growth of white  
n 1976 corresponded to a sharper decline in  
h of black cherry, probably due to defoliation  
e forest tent caterpillar (Anon. 1976).

basswood (*Tilia americana* L. [*Tilia glabra*  
J) was abundant only at this location. The  
es was classified as nitrogen-demanding by  
ell and Chandler (1939). Our results may not  
representative of this species, however, inasmuch  
veral trees at this location had damaged  
s. For example, a single tree representing  
half the initial basal area of basswood at the  
g/ha treatment level had lost most of its crown  
e the experiment was established in 1969. A  
rown had formed by 1979 and the tree appeared  
ous; growth, however, was still below rates of  
tilized trees of similar diameter. Growth at  
igh N rate was greater than at the low rates in

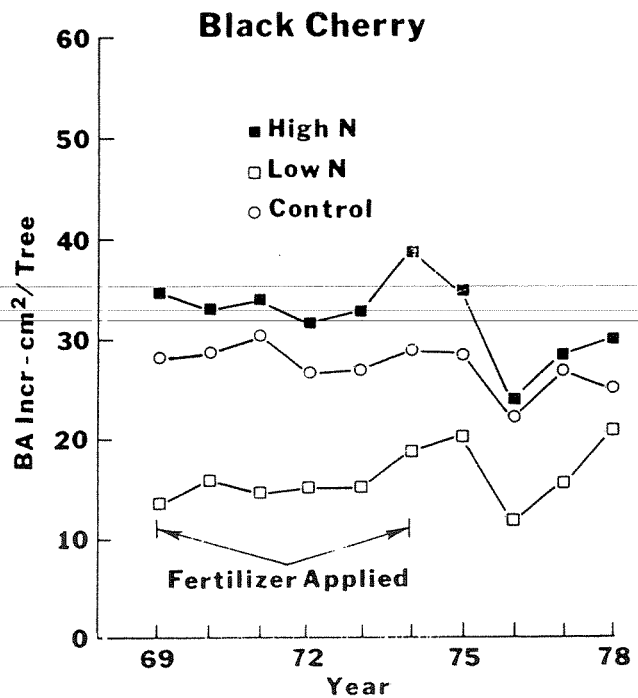


FIGURE 7.--Annual response of black cherry basal area increment to added nitrogen, Chenango Maple-Basswood.

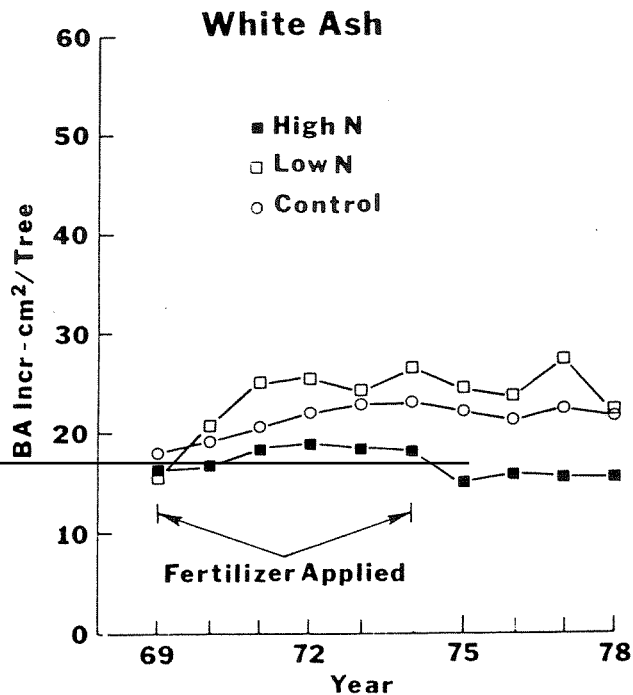


FIGURE 8.--Annual response of white ash basal area increment to added nitrogen, Chenango Maple-Basswood.



all years except the first and last (fig. 9) but the fertilized trees grew less than the controls in most years. There were no evident trends related to treatment. Basswood was not as obviously affected by the presumed defoliation in 1972 or 1976 as were black cherry and white ash at this location (figs. 7 and 8).

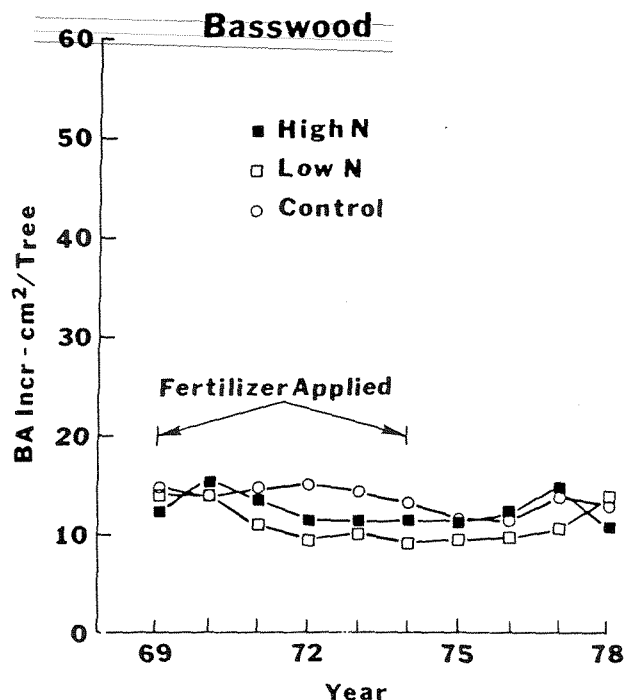


FIGURE 9.--Annual response of basswood basal area increment to added nitrogen, Chenango Maple-Basswood.

**SUGAR MAPLE.**--Response of sugar maple to fertilization at this location differed from that at other locations (fig. 10). Treatment effects were significant in all years (by analysis of covariance). Growth at the low rate was greater than the controls during the first 7 years, then fell below controls for the remainder of the experiment. Sugar maple fertilized at the high rate grew faster than controls for 3 years, then declined below the controls. Lea et al. (1979) reported that sugar maple responded positively to a combined treatment of thinning and fertilization at the rate of 275 kg/ha N. In the present study, the years of faster sugar maple growth corresponded to years of slower basswood growth, and vice versa. Thus, the positive response to added N may have resulted from less crown competition with basswood. This relationship was more pronounced than that of sugar maple with the growth of the less numerous black cherry and white ash.

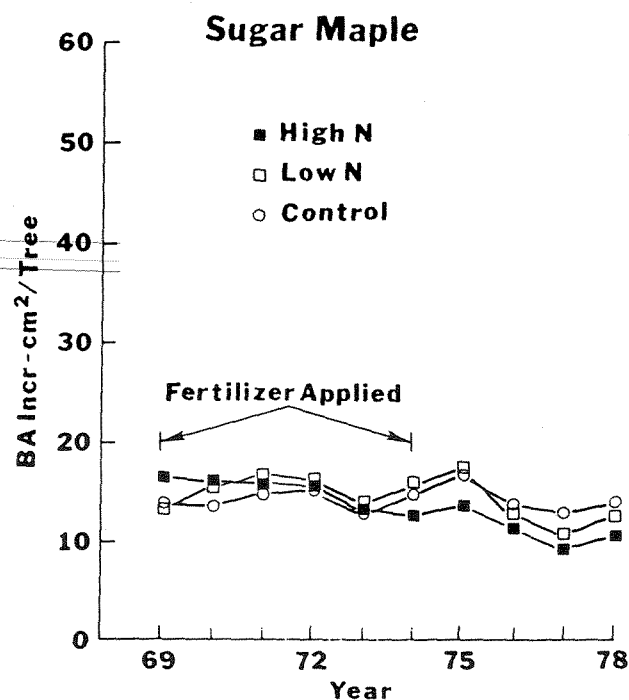


FIGURE 10.--Annual response of sugar maple basal area increment to added nitrogen, Chenango Maple-Basswood.

#### Conclusions

The same conclusion about response of black cherry and white ash to added N emerge, whether locations were analyzed separately or combined. Response of black cherry to N at the Schoharie location was not significant (by analysis of covariance), however, and growth at the three eastern locations (Chenango Black Cherry, Maple-Basswood, and Schoharie) was lower than at the western (Cattaraugus) location. This illustrates the value of a regional approach, with response at all locations assessed simultaneously; it also illustrates the desirability of a covariate that accounts for individual tree growth differences.

Where sufficient trees were present to allow comparisons among species, differential response was apparent. Thus, at Cattaraugus and Chenango Maple-Basswood, black cherry achieved best growth at the high-N rates and white ash at the low rates, in agreement with the pooled comparison that included other locations. Sugar maple response was variable. Overall, the response was one of declining growth over time, more pronounced at the higher-N rates. At the three locations where a positive response occurred, it was associated with temporarily lower crown densities of other species, whether by intentional thinning (Hooker Hill), differential defoliation (Cattaraugus) or crown damage (Chenango Maple-Basswood).

Sugar maple emerges as a remarkably unresponsive species compared with others. It grew less than any species at all locations, except that it was the same as red maple (Cattaraugus) and basswood (narrow-leafed Maple-Basswood). The species is capable of rapid diameter growth (e.g. Trimble 1968, 1969), the slower growth of pole-size sugar maple compared to other hardwoods (Godman In press) is probably an effect of density. D. Stone (1980), for example, found that the 10-year diameter growth of thinned sugar and red maple poles was negatively related with initial stand basal area. Other studies indicate that thinning is necessary to get a significant response to added N (Ellis 1979; et al. 1979; D. Stone 1980). As now seems apparent, total basal areas on many plots at the beginning of our experiment (table 1) were too high to get appreciable diameter response, and especially in the relatively small diameter of many trees. Thinning measurement to only dominant and dominant trees was not enough to overcome this effect. Excess basal area is probably a major factor in the widespread lack of response to added N.

Several points can be made about the conduct of fertilization experiments. Every tree ought to be measured and accounted for at each measurement. If mixed stands are so difficult to measure accurately any other way. This was certainly a major shortcoming in the conduct of our experiment. Each measurement point should be marked, because meter growth may be very slow. Stand basal area increase is not a satisfactory measure of response in such stands, even though they have been previously thinned. Stand basal area increase is small (because of density) and tree to tree variability high, even within the dominant and dominant classes.

Future fertilization experiments with northern hardwoods could explicitly consider the effects of size, species composition, and stand density, either through analysis of covariance using relative density, or by thinning and fertilizer combinations, both. In all cases, pretreatment growth rates should be examined for representativeness, and could be included in covariance analysis.

A promising area for further study is the interaction of nutrition and herbivory. Although interpretations of species growth differences based on mostly circumstantial evidence of defoliation, they are in accord with at least one documented instance. Hinckley and Lassoie (1981) give similar results following an outbreak of balsam-fir Tussock moth. Western larch (*Larix laricina* (DuRoi) Koch), a nonpreferred species, increased stem growth following the outbreak. The impact of defoliation on the preferred species, Douglas-fir (*Pseudotsuga mucronata* (Mirb.) Franco), varied by crown class; dominant trees were less severely affected than intermediate and suppressed trees. The measurement of defoliation impacts on growth is difficult (Man 1971) and introduces additional complexity in studies of the interaction of nutrition and herbivory.

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